Description of the NRL Radar Target Signature (RTS) Model

The Systems Analysis Section of the Radar Analysis Branch in the Radar Division of the Naval Research Laboratory has developed a set of analytical computer programs, collectively called the Radar Target Signature model or simply RTS, to model complicated structures such as ships and to calculate and analyze their radar signatures. The RTS model has been used within the U.S. Navy on the design of low radar signature ships such as the DDG-51 class and the LPD-17), and the retrofitting of existing ships such as the FFG-7, DD-963, and CG-47 classes for reduced signature.

The RTS model calculates the radar signature of a physical object using high frequency, scattering center techniques. The fundamental assumption of these techniques is that the object can be modeled as a collection of basic geometrical shapes called primitives with the total signature of the object being simply the coherent sum of the signature contributions of each of the individual primitives. The contribution to the radar signature of the individual primitives are found by RTS using standard physical approximations for calculating bistatic radar scattering in the high frequency region. In particular, RTS uses scattering equations from geometrical optics (GO), physical optics (PO), the geometrical theory of diffraction (GTD), and the physical theory of diffraction (PTD) to make signature calculations. Moreover, given that the objects of interest usually have linear dimensions on the order of thousands of wavelengths and are typically comprised of many thousands of primitives, the RTS model uses only closed form equations for calculating radar signatures because the use of integral or iterative calculation methods would be computationally impractical.

Using the RTS model, a geometrical description of the structure of interest is first created using the basic modeling primitives. The set of primitives used by RTS to model a complicated structure include the convex polygon, elliptic plate, elliptic cylinder, elliptic cone frustum, ellipsoid, elliptic hyperboloid, elliptic paraboloid, and torus. Moreover, using information contained in the geometric description, the RTS model automatically generates the scattering primitives which can occur at the boundary edges between the modeling primitives or among multiple modeling primitives. In particular, the RTS model automatically constructs straight edge, curved edge, elliptic tip, dihedral corner, trihedral corner, and multi-bounce-scatterer primitives. Whenever two polygon primitives share a boundary edge, a straight edge primitive is generated if the angle between the outward facing polygon surfaces is greater than 180° or a dihedral corner if the angle is less than 180° . Similarly, whenever two surface primitives share a curved boundary edge and the angle between the outward facing surfaces is greater than 180° , two curved edge primitives, a concave curved edge and a convex curved edge, are generated. The concave curved edge accounts the scattering contribution from the point on the physical edge furthest from the radar whereas the convex curved edge accounts for the scattering for the point closest to the radar. A trihedral corner primitive is generated whenever a set of polygon primitives share a common vertex, consist of three planar surfaces, and the angle between each of outward facing surfaces is less than 180° . The multi-bounce-scatterer primitives, which currently are restricted to ordered sequences of polygon primitives that could conceivably contribute to the signature for some bistatic transmitter and receiver configuration, are also automatically identified by the RTS model for any desired number of reflections.

The radar scattering from the flat and singly curved surface primitives, namely the polygon, elliptic plate, elliptic cylinder, and elliptic cone frustum, is calculated using PO. The scattering from the doubly curved surfaces, namely the ellipsoid, elliptic hyperboloid, elliptic paraboloid, and torus, is calculated using GO. The scattering from the straight edge and two curved edge primitives is calculated using PTD and the scattering from the elliptic tip primitive is found using GTD. The scattering contribution of an N-bounce multi-bounce-scatterer primitive is found by performing a GO reflection from the 1st polygon in the sequence to determine the illuminated portion of the 2nd polygon in the sequence, then performing a GO reflection from the illuminated portion of the 2nd polygon to find the illuminated portion of the 3rd polygon, and so forth until the illuminated portion of the Nth polygon is determined. The illuminated portion of the Nth polygon is then treated as a polygon primitive from which the scattering is calculated using bistatic PO. This process is then repeated in the reverse order from the Nth polygon in the sequence to the (N-1)th and so forth down to the 1^{st} polygon whose illuminated portion is treated as a polygon primitive from which the scattering is calculated using PO. The complete signature contribution of the N-bounce multi-bounce-scatterer primitive is the sum of the 1^{st} to the Nth polygon and the Nth to the 1^{st} polygon signatures. The signature of a dihedral corner is simply the signature of the single 2-bounce multi-bounce-scatterer between its two polygonal faces, and the signature contribution of a trihedral corner is the sum of all the possible 3-bounce multi-bounce-scatterers among its composite polygonal faces.

As the reflection of radar signals from the sea surface significantly affects the radar signature of ships, the RTS model calculates the contributions to the signature due to reflections from the curved sea surface. This phenomena is called sea multipath. Briefly, the transmitted radar signal can reach any scattering primitive via either a direct path from the radar to the scatterer or an indirect, sea-reflected path to the scatterer and, similarly, the scattered radar signal may return to the receiving antenna via either a direct or indirect path. Thus, the total signature contribution of each scattering primitive must include the contributions from the four possible transmit-receive paths, namely, the direct-direct path, the direct-indirect path, indirect-direct path, and indirect-indirect path. In addition, the direct-indirect and indirect-direct paths always require bistatic scattering calculations. The RTS model calculates the signature contributions of all four possible paths taking into account the curved earth geometry, the reflection properties of sea water, the refraction of radar waves by the atmosphere, and the sea state. In particular, in order to account for the refraction of electromagnetic waves propagating in the atmosphere, the RTS model calculates the curved earth geometry for every path, both direct and indirect, using the classical technique of replacing the actual earth radius R with an equivalent earth of radius kR and the actual atmosphere with a homogeneous atmosphere in which the waves propagate in straight lines. The value $k=4/3$ is typically used to get the equivalent earth radius for propagation over sea water, although the model allows the specification of any equivalent earth radius. Additionally, for each indirect path, the RTS model calculates the specular reflection point and the complex (i.e., amplitude and phase) reflection coefficient for the curved sea surface. The complex reflection coefficient is further resolved into three factors, namely, a highly polarization dependent reflection coefficient calculated using Fresnel’s equations for the reflection of a electromagnetic plane wave from a smooth, planar salt-water surface, a divergence factor to account for the fact that the physical process actually involves the reflection of a spherical wave from a spherical surface, and a factor based on sea state to account for the reduction in the reflection magnitude caused by the roughness of the sea.

The RTS model allows the assignment of radar absorbing material (RAM) to any of the basic modeling primitives. Within RTS, the effect of the RAM on the radar signature of a scatterer is determined by extracting from a pre-defined table the radar signal attenuation for the material at the appropriate radar frequency, transmiiter incidence angle, transmitter and receiver bistatic angle, and transmiiter and receiver polarization. Although the RTS model cannot currently calculate the attenuation factor for a material from its electromagnetic properties, the Radar Analysis Branch at NRL has another model for calculating radar signatures called the Integral Radar Target Signature (IRTS) model that can calculate the attenuation coefficients of materials from their electomagentic properties. Thus, when the elctromagnetic properties of a material, namely, the complex e and m as a function of frequency, are provided, the IRTS model can be used to generate the table of attenuation coefficients required in RTS.